Control of R.F. Interference

By JAMES HAWK

Some common causes of RFI and effective techniques that may be used to alleviate or eliminate this ubiquitous problem are discussed.

EVERY radioman knows the meaning of QRM and QRN, the international Q signals used to describe radio-frequency interference (RFI) by man-made signals and static. In the time since these Q signals were devised, impressive advancements have been made in communications systems, as well as in the control of RFI.

The performance of a communications system may be described using a probability of successfully transmitting and receiving a given piece of information between two points, either by wire or by radiation, based upon a signal-to-noise ratio and the modulation pattern. The threshold of the system is usually stated as "what the probability is along with other conditions of operation." All communications systems have such a threshold, and RFI is important to the extent that the threshold is adversely affected.

The control of RFI involves three things: signal characteristics, signal paths, and the mechanisms of interference, that is, the signal, the path, and the mechanism.

Investigation of the signal issue involves such things as waveshapes, frequencies, repetition rates, signal timing, levels, and similar characteristics of the interfering signal, and is not considered difficult or complicated. However, investigation of the path and mechanism of the interference problem is sometimes difficult, time-consuming, and complicated.

Interference Paths

The interfering signal usually enters the unit being interfered with by means of a signal path (control lines, oscillator inputs, etc.), a common-ground impedance, or a power-supply voltage.

Coupling to the signal route of entry occurs by means of electromagnetic radiation, transformer coupling, capacitive coupling, or by means of circuit coupling to the signal wire itself from within another unit. Particularly difficult RFI problems are developed when combinations of these entry points and coupling paths exist. The conventional theories regarding radiation, transformer action, and capacitance are used in the evaluation of the means of coupling. A change in the physical distance between the coupling elements involved will usually provide sufficient diagnostic data.

The correction of problems associated with common grounds and common power-supply voltages can be difficult if consideration has not been given to these problems during the design phase of the equipment. This is especially true in the case of common-ground impedances that are frequently developed from chassis elements such as mounting frames, racks, or drawers, which cannot be easily changed.

For some kinds of common-ground impedance problems, the RFI may become worse with the use of low-resistance ground straps. An example of this is shown in both Fig. 1, a pictorial presentation of how a common-ground impedance might be developed and Fig. 2, a schematic representation of the same situation. In Fig. 2, the voltage across $R1$ will be the sum of the battery voltage and the voltages across $R3$ and $R4$. The voltage developed across $R4$ is a function of the ground currents of both the radio and the ignition unit. Thus, the voltage across $R1$ will have a component which is a function of the current drawn by the ignition unit. The lower the value of $R2$, which is the resistance of the ignition unit ground path, the higher the interference voltage across $R1$. The interfering signal in this case would very likely take the form of ignition interference on AM reception, especially in areas of weak AM signals. If an electronic capacitor-discharge ignition system were being used, the interfering signal could include a harmonic of the d.c.-d.c. converter operating frequency.

In such interference cases, the correct thing is to separate the two ground paths completely, as shown in Fig. 3. Low-resistance ground straps are then helpful, as they reduce the I^2R losses of both $R2$ and $R3$. The same kind of problem can exist with signal-ground paths, as well as battery or power-supply ground paths.

The configuration shown in Fig. 3 (ground paths separated) still has the internal impedance of the battery in common, as well as the battery's hot terminal lead, either of which may give rise to an RFI problem. However, it's worth remembering that when everything possible has been done to reduce the RFI caused by the power-supply leads, or by the internal-source impedance of the battery or power supply, prohibitive interference may still exist as a consequence of a common-ground impedance path.

RFI problems, as a consequence of common power-supply voltages, are familiar problems and are usually dealt with by using decoupling networks and in-line filters. Even though power-supply leads only carry d.c. currents and voltages, they are also capable of carrying and transmitting a wide variety of interfering signals unless specific provisions, such as shielding and isolated routing, are taken to prevent them from doing so. Also, while the d.c. currents travel in one direction through the wires, the interfering signals may travel in either direction. Having one large power supply service many chassis should be avoided as it leads to a

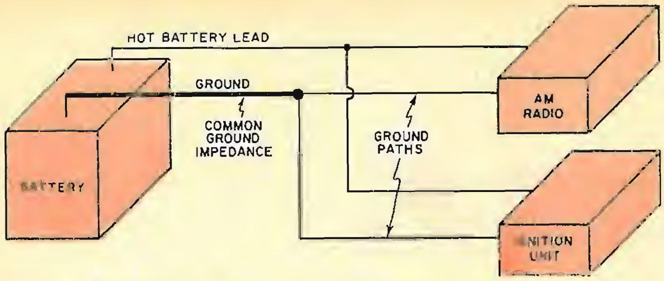


Fig. 1. Diagram showing how a common-ground impedance, a cause of RFI, develops between a car's AM radio and ignition.

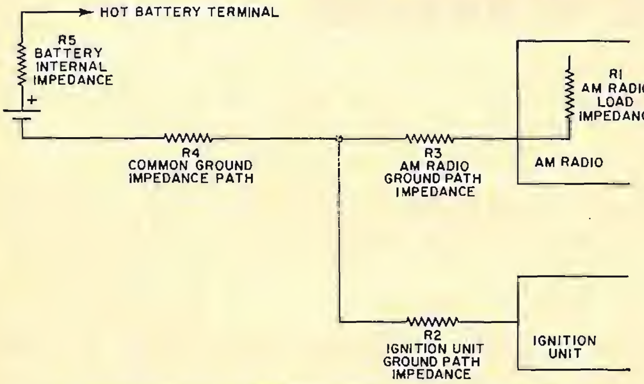


Fig. 2. Schematic of common-ground impedance path. The lower the value of R2 the higher interference voltage across R1.

variety of power-supply problems of which RFI is one.

The internal impedance of a power supply can cause RFI in the same fashion as the common-ground impedance path, even though the power supply, because of electronic regulation, has a very low source impedance. This may be especially true when the power supply is used to provide energy for a d.c.-d.c. converter, as the switching times of the converter are fast and current demands large. In such cases, an in-line filter or a decoupling network should be used with power-supply leads that are between units susceptible to interference.

Thresholds

The effectiveness of most variations of the three most popular methods of modulation, AM, FM, and PM, is oftentimes expressed in terms of how the modulation intelligence is utilized after its removal from the r.f. carrier, the measurement of which is sometimes subjective. Consider, for example, the question of how much noise can be tolerated by a TV viewer while watching an old movie *versus* that which can be tolerated while watching an art show. Attempting to improve an RFI situation, using such criteria, can be frustrating and ineffective. It's better to relate the post-detection signal-to-noise ratio to the pre-detection signal-to-noise ratio using whatever threshold criterion is convenient, and then, while using the pre-detection signal-to-noise ratio as a standard, perform the testing and measuring at the lowest i.f. frequency. The lowest i.f. frequency is usually convenient in terms of test equipment and test techniques.

The most sensitive threshold point to use in determining just how much RFI energy is present is the point at which the noise power just equals the signal power within a known noise bandwidth and in a channel with linear gain. This point is found by first establishing the amount of noise power at the input of the receiver.

The noise power in a one-hertz bandwidth presented to the matched input of a receiver at room temperature is about −174 dBm, and for noise figures greater than 10 dB the amount of power may be increased by the amount of the noise figure with very little error. For noise figures less than 10 dB, increasing the amount of noise power by the noise figure will result in an error which will increase in magnitude as the noise figure decreases. (See "Low-Noise Receiver Performance Measurements," ELECTRONICS WORLD, March 1969 issue.) To determine the amount of noise power in a known noise bandwidth, the noise power at the input is increased by the amount of noise bandwidth expressed in dB. For example, a receiver with a noise figure of 10 dB and a noise bandwidth of 100,000 Hz would have an input noise power of: −174 dBm −10 dB (receiver noise figure) −50 dB (100,000-Hz noise bandwidth expressed in dB) or −114 dBm per 100,000 Hz.

A signal generator connected to the input of the system would cause an r.m.s. meter to read 3 dB higher (3 dB = double the power) when its output was adjusted from zero to −114 dBm, because the signal power would then equal the noise power. This equal-power point is very sensitive to power-level changes in either noise or signal and is thus an excellent indicating point for observing changes in the RFI status.

Mechanisms

The mechanism of interference invariably depends upon the modulation scheme employed. Impulse noise has a much different effect upon a conventional AM system than it does upon an FM or PM system. A few strong noise pulses can seriously interfere with a digital-modulation pattern, and have negligible effect upon an FM/FM scheme. In addition to the variations among systems in terms of the RFI impact, there is the variation of interference effects upon different kinds of circuits. Circuits such as oscillators, mixers, amplifiers, limiters, modulators, demodulators, and switching elements, have their own RFI susceptibility pattern. Consequently, depending on the circuit, the RFI problem can be solved by modifying the circuit mechanism either by adding or subtracting gain, balancing a previously unbalanced demodulator, or placing the entire circuit in a separately shielded enclosure.

Control Techniques

The control of signal-ground impedances is sometimes accomplished by using a balanced-transmission system with an optional center-tap ground (Fig. 4). Most problems involving common-ground paths are avoided and, if tuned transformers are used, the system is then frequency-selective, which is an additional aid in avoiding RFI problems.

In addition to the grounding advantages, the balanced-

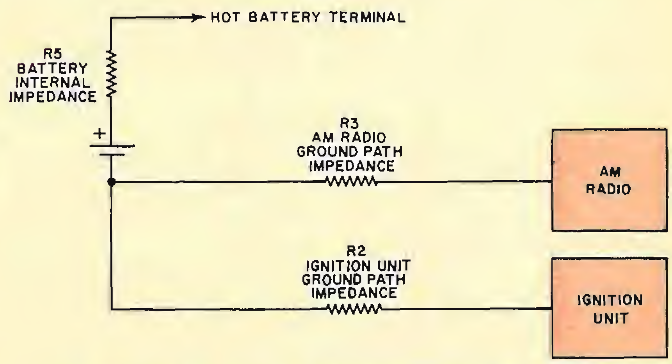
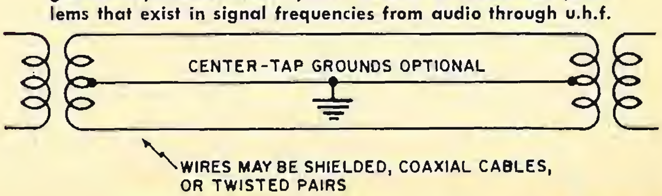


Fig. 3. Schematic showing common-ground impedance paths separated to reduce RFI. Battery's internal and hot-lead impedances are sources that may give rise to RFI problems.

Fig. 4. Balanced transmission system used to control signal-ground impedances. This system is used to reduce RFI problems that exist in signal frequencies from audio through u.h.f.



transmission system is a very poor performer as an antenna system, both for receiving and transmitting interfering signals. Received electromagnetic radiation will cause essentially equal and opposite currents to flow in the center-tapped windings, with a resulting small-current flow in the single-ended windings. Electromagnetic radiation, as a result of signal-current flow through the balanced lines, will be very small due to the negating effects of opposing signal currents. From an RFI viewpoint, the balanced system should be used for signal frequencies ranging from audio through u.h.f.

Coaxial lines which form an unbalanced-transmission system are sometimes grounded through a special coupling device which blocks d.c. and other low-frequency currents, while maintaining the integrity of the characteristic impedance of the coaxial line at the signal frequency. Such coupling devices are essentially capacitors that have been mechanically designed to be connected directly between a panel connector and the cable.

Various grounding schemes have been devised and incorporated into military and commercial specifications that handle the RFI problems effectively and directly. However, factors such as cost and schedule occasionally necessitate that the more effective specification requirements be ignored. In addition, in such cases, as when a single-point grounding concept cannot be implemented, the grounding schemes should be implemented to whatever extent possible.

A separate power-supply lead, shielded with inexpensive, high-capacitance-per-foot-rating shielded lead, should be provided for each service load. The shield should be grounded at both ends and, as often as possible in between, unless an over-all grounding scheme is being implemented and dictates to the contrary, or unless RFI tests result in a more effective grounding pattern being established. Another approach that is sometimes effectively employed, is to use an insulated shielded lead so as to be able to control the grounding points in between the two terminal ends.

Coaxial cables, used as part of a flat-transmission system, are very effective in terms of reducing RFI problems, since they become poor antennas when properly matched with their characteristic impedance. In particularly sensitive applications double-shielded cable may be used and sometimes, to minimize multiple reflections, it becomes important to terminate the cable in its characteristic impedance at both the source and load ends so as to maintain a flat line for signal currents flowing in either direction.

Connectors should be selected with RFI in mind. Flat-transmission systems should be used for all signal frequencies, video and above, and the connectors used should maintain the integrity of the coaxial impedance. Audio signals should be routed at an impedance level of 600 ohms, for a variety of reasons other than those solely associated with RFI problems, and be routed through ordinary connectors provided that the signal is not low and followed by high-gain phono, tape, or microphone outputs. In such cases, connectors which maintain the shielding integrity should be used.

The control of RFI is greatly enhanced if the various signal levels are standardized so as to avoid large differences in relative power levels; more than 20 dB or so. It's easier to avoid interference problems between two signals which are both 1 mW than between signals with relative-amplitude differences of 50 dB. A high-voltage signal should not be routed close to a high-impedance signal path.

In-line filters are often suggested as a solution to various RFI problems, particularly when the interfering signal enters the system through the primary channel. The filter itself usually has an insertion loss, sometimes as high as 20 dB, and its use therefore involves an adjustment of the gain constants of the channel. The chances of successfully making such an adjustment are greatly improved if the possibility of the need for such a filter is kept in mind while designing the gain assignments and the signal interfaces. In-line filters are generally useful in dealing with adjacent-channel interference.

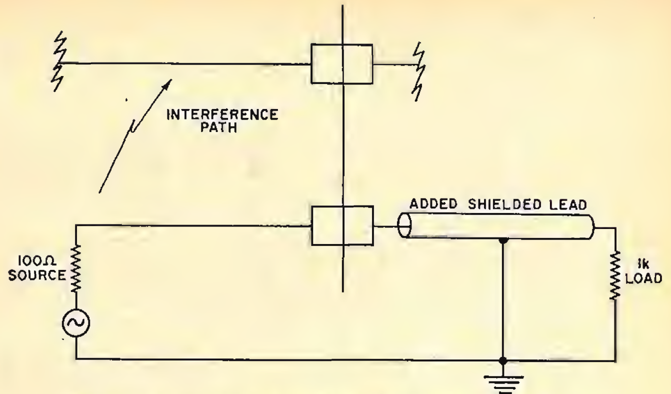


Fig. 5. An example illustrating where, by the addition of a shield to decrease RFI, the opposite effect actually occurs.

The majority of RFI problems are caused by signal leads being coupled, even though the more difficult problems involve common-impedance paths. In solving RFI problems, most of the time is usually spent on changing signal routes, shield grounds, and connector arrangements.

The RFI problem, due to electromagnetic radiation, may sometimes be dealt with by considering the interference system as a transmitter, a transmitting antenna, a receiving antenna, and a receiver. Maximum power is delivered to the transmitting antenna when the source impedance of the transmitter is the conjugate match of the antenna impedance, and the same relationship is true for the receiving antenna and the receiver. In the case of an RFI problem it would be unusual if a match existed between a given antenna and its transmitter and receiver. Thus, a change in the impedance values is just as likely to improve impedance match as it is to make it more of a mismatch.

An improvement in the impedance match is likely to result in a degradation of the RFI situation. Consider, for example, the setup shown in Fig. 5 where the source impedance is 100 ohms and the load impedance is 1000 ohms. If a shield is installed on the right-hand section of the signal lead, as shown in the diagram, the load impedance as seen from the source will be lowered, causing more signal current to flow through the signal lead. More signal current will result in a higher level of radiation with an accompanying increase in interference. In this particular case the addition of a shield, in an effort to destroy the effectiveness of the signal wire as an RFI source, made the problem worse. The correct thing to do is to shield the entire length of the wire and, using a shielded connector, route the wire through the bulkhead. The shield may be grounded in several places. However, the addition of the shield and its grounding may give rise to common-impedance problems, indicating that the best grounding approach can be accomplished most easily by trial and error.

If a frequency difference exists between the interfering signals, much can be done to destroy energy transfer at the unwanted signal frequency. A frequency-selective filter consisting of a capacitor or an inductor, or both, in combination with a resistor, will give excellent results. A filter consisting of several poles may be used, depending upon the particular problem or application.

RFI problems are sometimes the most difficult aspect of equipment testing and operation, and the establishment of sensible threshold criteria may be the key to the problems' solution. ▲

(Editor's Note: Readers of this article will be interested in a special series of articles covering "Shielded Cables and Connectors" and "Filters" which appeared in our October 1968 and April 1969 issues, respectively.)